# A National Program of Research for

# WEATHER MODIFICATION

Prepared by

A JOINT TASK FORCE OF THE
U. S. DEPARTMENT OF AGRICULTURE
AND THE STATE UNIVERSITIES
AND LAND GRANT COLLEGES

# FOREWORD

The United States Department of Agriculture and State Agricultural Experiment Stations are continuing comprehensive planning of research. This report is a part of this joint research planning and was prepared under recommendation 2 (page 204, paragraph 3) of the National Program of Research for Agriculture.

The task force which developed the report was requested to express their collective judgment as individual scientists and research administrators in regard to the research questions that need to be answered, the evaluation of present research efforts, and changes in research programs to meet present and future needs. The task force was asked to use the National Program of Research for Agriculture as a basis for their recommendation. However, in recognition of changing research needs it was anticipated that the task force recommendations might deviate from the specific plans of the National Program. These deviations are identified in the report along with appropriate reasons for change.

The report represents a valuable contribution to research plans for agriculture. It will be utilized by the Department and the State Agricultural Experiment Stations in developing their research programs. It should not be regarded as a request for the appropriation of funds or as a proposed rate at which funds will be requested to implement the research program.

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This report has been prepared in limited numbers. Persons having a special interest in the development of public research and related programs may request copies from the Research Program Development and Evaluation Staff, Room 318-E Administration Bldg., USDA, Washington, D.C. 20250.



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# WEATHER MODIFICATION
# FOR AGRICULTURE AND FORESTRY

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# PREFACE

This report presents a national program of research and development in weather modification for agriculture and forestry. The recommended program supplements A National Program of Research for Agriculture.

The research and development program concerns direct modification of weather and the resulting biological, economic, and social consequences of weather modification. The output from this program will contribute to knowledge and technology urgently needed in the total enterprise of agriculture and forestry. Moreover, it will provide the basis for essential decision making on weather modification programs affecting nearly every aspect of agriculture and forestry.

The recommended research and development program has been prepared in an environment of intense scientific interest and progress in weather modification. Recent major studies and reports by the National Academy of Sciences-National Research Council and the National Science Foundation emphasize that weather modification offers a tremendous potential for benefit of mankind and that now is the time for action in developing needed research programs. The interdepartmental Committee on Atmospheric Sciences (ICAS) has given continuing attention to these matters and has prepared specific recommendations for a coordinated Federal program. Results of Federal weather modification research, funded at more than $11 million in FY 1968, and from other scientific effort in this country and abroad establish a launch point for expanded future research programs. Moreover, inhouse research within the Department of Agriculture, such as the Forest Service's project Skyfire, one of the oldest and most productive weather modification research projects in the U.S., provide the level of scientific expertise and experience needed to effectively plan a much increased total effort. All of these activities have provided background reflected in the recommendations of this report.

The research and development program is planned for performance by agencies of the U.S. Department of Agriculture and by the State Agricultural Experiment Stations. This work will be carried out both internally within each organization and through grants, contracts or cooperative agreements, depending on the nature of each task. The report recommends Federal involvement and investment by program levels in each major phase of research and development activity for fiscal years 1972 to 1977.

The recommended program and report was prepared by a Task Force representing U.S. Department of Agriculture agencies, State Agricultural Experiment Stations, and cooperating organizations as follows:

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# I. NATIONAL GOALS

During the last twenty years, man has gradually learned that weather can be modified. The potentials for full development of weather modification science and technology present an enormous challenge. This challenge to agriculture and forestry, as in other weather affected programs, is:

Learn how to manage the atmosphere for the benefit of mankind.

## A. Basic Goals and Benefits

The basic goals and benefits of weather modification for agriculture and forestry are:

1. Food for a Growing World Population.

   Weather modification has a significant potential for increasing and stabilizing food production. Learning how to manage the atmosphere may be as important to agriculture as have been the developments in fertilizers, pesticides, improved genetic materials and soil management. A new potential for enhancing food production on high yielding lands can come from augmenting and regulating precipitation, preventing hail and minimizing frost and wind damage. Production also can be extended to lands which are now marginal.

2. Fiber for the National and World Economy

   Timely modification of precipitation and prevention of lightning and hail provides new opportunities to manage effectively fiber production systems and to protect crops and forests from storms or fires. Weather modification can become an important new technology for increasing yields from forests lands.

3. Safeguarding Life and Property

   Weather modification provides a new and powerful method for safeguarding human life and protecting property in forest, range and agricultural lands. Preventing forest and range fires, eliminating property-damaging hail, and reducing winds from severe storms are benefits which weather modification can make possible.

4. Protecting Quality of Man's Environment, Natural Beauty and Outdoor Recreation

Weather modification research can provide new ways of developing and maintaining a quality environment in America. Both air and water for man's health and well-being can be improved through man's modification efforts. Green countryside, majestic forests, bold flowing streams, unparched wild lands, teeming wildlife and beautiful recreation lands can all be fostered by weather modification practices. Man also must learn how to protect his environment from inadvertent modification and from possible harmful side effects of deliberate weather change.

5. Enhancing Water Resources

Weather modification can increase water available for agriculture, industry, and domestic use from forest, range and agricultural areas. Timely increases of precipitation and snowpack on forest and range watersheds will increase the storage and the supply of water for farms, cities and industries. Prevention of forest fires can help insure even flows of clean water.

B. Opportunities and Needs in Weather Modification

Although knowledge and technology are only in the preliminary stages of development, it is clear that the potential consequences of weather modification can affect nearly every aspect of agricultural and forest resource management. The challenge to exploit our weather modification capabilities carries a mandate for the scientific community to develop the knowledge and technology which will permit society to receive maximum benefit from intentional weather modification.

One of the great potential achievements of intentional weather modification is the increase and stabilization of the supply of food, fiber, and timber of the world, for drought and cold are among the greatest limiters and destroyers of crops. Prevention of damage from hail, fire, and severe winds will surely benefit farm and forest enterprise; forests, in particular, will be better protected from lightning-caused fires and disastrous conflagrations. Possibilities exist for augmenting water supplies to plants and animals and beneficially changing the landscape.

Weather modification may be a two-edged sword. There is a potential for both beneficial and adverse effects. Sustained alteration of atmospheric behavior, if carried on without knowledge of possible consequences, may result in damage in excess of benefit. Biological systems can be altered in either desirable or undesirable ways. The physical landscape and the hydrological cycle may be changed beneficially or may be damaged. Fire

igniting lightning strokes may be triggered rather than prevented through application of improper weather modification techniques.

In addition to deliberate weather modification, inadvertent weather modification has resulted from our wastes vented to the air and from unnecessary, man-derived dusts and aerosols. The nation must know how inadvertent weather modification by atmospheric pollution affects plants and other organisms, including man, and must either ameliorate adverse conditions or adjust to them. Indeed, recognizing the biological consequences of atmospheric degradation may be less flamboyant than either nuclear or space research, but is of more immediate and greater consequence to man.

Learning how weather modification, deliberate or inadvertent, will change our crops, forests, other biological systems, and our landscapes should be a national goal of prime importance. Our survival and future prosperity may well depend on our ability to establish rational limits to atmospheric pollution, and to safely modify the weather. The only possible avenue to beneficial exploitation of intentional weather modification and protection from harmful inadvertent atmospheric modification is a strong program of research and development. Both experimental and operating programs are already advancing under several Federal, state and private agencies. Agricultural and forestry programs may be affected more by weather modification than any other sector of the economy. It is imperative for the Department of Agriculture and the State Agricultural Experiment Stations to perform the research and development which will permit full realization of potential benefits and adequate protection of agricultural and forestry interests. The USDA and SAES must be full contributing members in the total national weather modification program.

## C. Summary of specific goals and level of effort

Intensive national efforts have developed essential background for planning the research and development program. This background comes, first, from the results of some 20 years of research as well as active cloud seeding operations which followed the pioneering experiments by Schaefer and Langmuir in 1946. It also comes from several decades of experience in the related agricultural and forestry sciences and from recent, spectacular developments in physical and engineering sciences which establish new capabilities for the recommended research. As a result it is now possible to present the following specific program elements for agricultural and forestry research in keeping with national goals and to have ample reason to expect their fulfillment for the benefit of mankind.

### 1. Direct Modification of Weather

a. Develop weather modification technology to accomplish precipitation modification for agricultural production and forest protection.

b. Suppress lightning fire ignition and lightning damage in forest and range lands.

c. Suppress hail damage to agricultural crops and resources.

d. Modify local winds, temperature and radiation for protection of agricultural and forest resources.

The recommended levels of research and development for this program element are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man Years | 43 | 81 |
| Thousands of Dollars | 4,975 | 10,470 |

2. Biological and Hydrological Consequences of Weather Modification

a. Assess the impact of weather modification upon biological systems.

b. Assess the impact of weather modification upon the physical landscape and the hydrological cycle.

c. Learn how micrometeorological processes in the soil-plant-air layers interact with changes in weather systems.

d. Monitor biological changes at sites of experiments and active operations in weather modification.

e. Develop improved agricultural and forestry husbandry to exploit weather changes.

The recommended levels of research and development for this program element are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man Years | 59 | 114 |
| Thousands of Dollars | 3,730 | 8,280 |

3. Economic and Social Aspects of Weather Modification.

a. Assess the economic effects of weather modification on agricultural and forest resource management, production and protection.

b. Develop knowledge for attacking social and legal problems associated with weather modification.

The recommended levels of research and development for this program element are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man Years | 18 | 39 |
| Thousands of Dollars | 810 | 1,950 |

4. Decision Making in Weather Modification.

Develop knowledge for decision making and resolving policy issues in weather modification.

The recommended levels of research and development for this program element are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man Years | 4 | 8 |
| Thousands of Dollars | 240 | 480 |

The Department of Agriculture and the State Agricultural Experiment Stations can develop research resources for this total program from an already strong base. Agricultural and forestry research has long experience in direct modification of weather, and associated biological, ecological, economic and social problems. While substantial new resources of scientific manpower and facilities must be acquired for the recommended program, a significant part of these requirements can come from reprogramming existing efforts which weather modification itself, as well as other scientific developments have placed in a changed situation.

The total program requires a research and development level of 124 scientist man-years and $9.8 million in FY 1972 and strengthening to 242 SMY's and $21.2 million in FY 1977.

# II. A NATIONAL RESEARCH AND DEVELOPMENT PROGRAM

This program is recommended for performance by USDA agencies and the State Agricultural Experiment Stations. The work will be carried out wherever there is greatest competence for specific research and development tasks and where there is best opportunity for timely and efficient progress. This means that the work may be performed in-house by USDA agencies and State Agricultural Experiment Stations or by grants, contracts and cooperative agreements with universities, and other state, private or Federal research organizations.

Nearly all aspects of the program will be carried out in close cooperation with other government agencies having responsibilities and interests in weather modification. The research and development tasks in direct modification of weather will be performed wherever feasible and desirable in cooperation with the programs of the National Science Foundation, Department of the Interior, Department of Defense, National Aeronautics and Space Administration, Atomic Energy Commission, Environmental Science Services Administration of the Department of Commerce and other agencies. Similar cooperative programs will be performed in studies of the biological effects and economic and social aspects of weather modification.

The needed program levels in FY 1972 and FY 1977 are presented in terms of number of scientist man-years and dollars. The scientist as used in this report means a competent professionally trained individual at the GS-11 or higher level in government service or at equivalent level in universities or other organizations. Dollars also are used to express program levels because number of scientist man-years alone is meaningless in describing weather modification research and development costs. Requirements for technicians, equipment, aircraft operation, performance of large-scale field experiments, computer time and laboratory facilities vary widely according to the nature of each task. Therefore, dollars are used as an essential description of program levels. The dollar values are 1968 and must be adjusted according to value changes in future years. Major capital investments are identified separately.

## 1. DIRECT MODIFICATION OF WEATHER

Research on direct modification of weather is fundamental to the planned program. The Department of Agriculture is one of the pioneer agencies in weather modification. Project Skyfire, the USDA Forest Service research in lightning suppression is the oldest, continuously performed research project in weather modification in the United States. This research effort has not only pioneered approaches to lightning suppression, but

also has developed knowledge and technology contributing to general advancement of weather modification. These developments coupled with advances achieved in other weather modification research and in the whole field of atmospheric sciences provide a substantial foundation for the planned USDA-SAES program.

Agriculture and forestry receive more direct effects from weather modification than any other enterprise. If agricultural and forestry programs are to fully realize the benefits of weather modification, appropriately contribute to development of science and technology in this field, and, in fact, to control destinies in their assigned missions, they must become fully involved in direct modification of weather. Every fire setting lightning strike prevented, every hailstorm suppressed, and every cloud seeding operation that alters precipitation vitally influences agricultural or forestry programs. The recommended research and development program in direct modification of weather is aimed specifically at insuring that USDA-SAES will make the necessary scientific advances for achievement of established missions.

Research in direct modification of weather involves a variety of research and development activities. Many of these will be performed in cooperation with other agencies. The activities vary from basic research of atmospheric behavior to systems development for specific weather modification programs. All require advanced application of atmospheric, physical and engineering sciences. In particular, the research immediately ahead requires assembly and management of resources for the performance of large-scale experiments in lightning and hail suppression. These experiments will involve sophisticated instrumentation, operation of a modest sized fleet of aircraft, extensive logistic support of field operations, new designs for physical and statistical evaluations of results, special methods for data collection, retrieval and processing by computers, laboratory support for allied studies and small-scale tests, and strong scientific leadership of an interdisciplinary group of scientists and technicians. Administrative management for these activities must recognize and their budgets must reflect that this program requires deviation from standard formulas for scientist man-year costs and traditional methods of research planning, organization and coordination.

Task 1-a. Develop weather modification technology to accomplish precipitation modification for agricultural production and forest protection.

In the national program of weather modification, several agencies are performing activities in precipitation modification. The Department of Interior is carrying out programs to develop atmospheric water resources through precipitation increase. Much of this work is now being carried out or is planned over forest and agricultural lands. Some of the major

precipitation increase experiments and operations are on National Forests. The Environmental Science Services Administration is investigating precipitation modification processes and is planning field experiments. The National Science Foundation supports research performed by universities and other groups on the physics of precipitation mechanisms as well as field experiments in precipitation modification. In addition, several private concerns annually carry on cloud seeding activities aimed at precipitation increase. All of these activities are of vital concern and interest to agriculture and forestry. They involve all agricultural and forest regions of the United States.

With the exception of research related to forest fire control, it is not recommended that the USDA-SAES program include separate cloud seeding experiments for precipitation modification. This work can be performed adequately by Interior, ESSA and NSF. However, it is essential for USDA and SAES to fully participate in the planning and fielding of all such programs.

An adequate USDA-SAES research capability must be developed so that agriculture can fully benefit from precipitation modification. We must be sure that precipitation modification experiments yield the type of data and knowledge permitting full understanding of their full impact on agricultural crops and resources.

The specific precipitation modification research task elements to be performed by USDA-SAES in cooperation with other agencies include:

(1) Identify specific agricultural benefits from precipitation modification in each major climatic region of the United States.

(2) Participate on an interagency basis in a series of studies and field experiments of precipitation modification in various agricultural regions and evaluate the results.

(3) Establish a program for effective use and control of the the resulting technology in agricultural regions.

The possibility of precipitation increase as an aid in the prevention and control of forest fires requires thorough study. Preliminary investigation of this possibility has been made by the U.S. Forest Service. Experiments of cloud seeding to stimulate precipitation in forest fire zones have been performed in Canada and Australia. It is essential that well planned experiments be carried on over selected forest regions in the United States. These experiments to be performed during forest fire seasons will involve a different set of atmospheric and operating conditions than the precipitation modification investigations performed by

other agencies. Therefore a fourth task element in the research and development program is recommended:

(4) Perform field experiments to determine the possibility of aiding in the prevention and control of forest fires through stimulation of precipitation over dry forests and forest fire zones.

The recommended levels of research and development for performance of this task are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 12 | 27 |
| Thousands of Dollars | 1,000 | 2,220 |

Task 1-b. Suppress lightning fire ignition and lightning damage in forest and range lands.

Annually some 10,000 to 15,000 forest fires in the U.S. are ignited by lightning. In the western states, lightning is the greatest single cause of forest fires. The cost of controlling lightning fires amounts to as much as $75 million per year. These fires cause great damage to commercial timber, recreation areas, watersheds and forest resource based industries and communities. They also take a toll of human lives, destroy homes, damage utilities and communication systems, and prevent orderly management of forest resources.

Project Skyfire, the USDA Forest Service lightning research program, is exploring the possibilities that cloud-to-ground lightning strokes may be prevented by special weather modification techniques. This research, carried on continuously since 1953 has developed much new knowledge of mountain thunderstorms and has pioneered new technology for lightning suppression experiments. The results include development of a thunderstorm model, lightning sensor systems and high output silver iodide generators for cloud seeding. The type of lightning discharge most likely to ignite fires has been identified. Pilot field experiments of lightning suppression have shown one-third less cloud-to-ground lightning from seeded clouds. Analyses are being made of the significance of these results. In addition, theoretical and laboratory studies have established the physical basis for lightning suppression through cloud seeding with ice forming nuclei. In laboratory experiments, ice crystals reduce the sparking potential of air across a gap. Moreover, field experiments have shown that massive glaciation in supercooled clouds may be achieved with Skyfire airborne silver iodide generators at warmer temperatures than heretofore believed possible. This development in cloud seeding and technology is of great significance to lightning suppression as well as to other weather modification activities.

The work performed to date has established a solid foundation for a research and development program having a high potential for success in lightning suppression. It is essential that large-scale field experiments be performed to fully develop and test methods for the prevention of fire igniting lightning strokes. These experiments should be performed in major lightning fire zones of the Western United States. Building on the results already achieved, it is also essential to develop technology and systems for the tracking and sensing of lightning storms so that seeding targets may be selected and results analyzed.

The research and development task elements to be performed include:

(1) Develop information on the characteristics of lightning strikes and storms.

(2) Develop systems for sensing, measuring and analyzing lightning strikes and storms so that times and places for lightning suppression operations may be properly identified.

(3) Perform theoretical and laboratory studies of mechanisms of lightning and lightning suppression.

(4) Perform large-scale field pilot projects for lightning suppression.

(5) Develop operational technology for lightning suppression.

(6) Develop operational systems for lightning suppression.

(7) Establish an operational program to be carried on by forest fire control agencies.

In view of the serious lightning fire problem as evidenced by recent disastrous conflagrations in the West and the opportunity to save great costs and resource losses through weather modification, the lightning suppression research program should have high priority.

The recommended levels of research and development for performance of this task are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-years | 12 | 20 |
| Thousands of dollars | 1,800 | 3,500 |

Task 1-c. Suppress hail damage to agricultural crops and resources.

Hail is a severe weather phenomena causing intense damage to agricultural resources. Crop hail insurance purchased by farmers costs some $116 million annually. The volume of crop hail insurance reached an alltime high of $3.1 billion in 1965. Hail accounts for about 11 percent of total loss payments from all types of Federal crop insurance. Hail is most frequent in the Mountain and Plain States, but also causes severe damage in many other states.

Weather modification offers the best possibility conceived to date for the suppression of hail damage. Although man has imperfect knowledge of hail processes, theoretical studies and exploratory experiments provide a strong basis for expecting that hail may be suppressed through cloud seeding. The Russians have reported significant hail suppression from supercooled clouds bombarded with silver iodide shot from rockets and artillery shells. USDA cloud seeding experiments, performed as a part of Project Skyfire, have shown that massive glaciation can be achieved in supercooled clouds at temperatures as warm as -7°C. These same experiments also show a strong correlation between lightning and hail. Cloud systems producing the most lightning also produce the most hail. The results of lightning suppression research provide a substantial foundation for the performance of similar experiments to test the hail suppression potential of "overseeding" techniques.

A national plan for hail suppression research has been developed by the National Science Foundation in cooperation with several Federal agencies and universities. Exploratory field experiments are being planned by ESSA, NSF, the National Center for Atmospheric Research (NCAR), Colorado State University and others. USDA has been asked to participate in these efforts. Agriculture has a key role to perform in the total national program because it is agriculture that is most affected by hail. Moreover, USDA scientists have essential background and expertise for both direct modification experiments and for application of hail suppression to specific agricultural crop situations.

Technical weather modification approaches for lightning and hail have many similarities. However, the mountain thunderstorm producing lightning over forest regions and the flatland storm producing hail over agricultural regions are substantially different. Therefore, separate experiments and field experimental areas will be required. The hail suppression research program can benefit from a close association with the lightning suppression research groups. Joint efforts including some pooling of personnel and equipment appears feasible. In addition, the hail suppression research program should be carried out in cooperation with other Federal agencies including ESSA, NSF and Interior.

The research and development task elements include:

(1) Identify pertinent atmospheric factors in each major area of the United States that might receive specific benefits from a hail suppression program.

(2) Develop systems for sensing, measuring and analyzing hailstorms so that times and places for hail suppression operations may be properly identified.

(3) Perform theoretical and laboratory studies of mechanisms of hail formation and hail suppression.

(4) Develop technology for hail suppression.

(5) Perform large-scale field pilot projects for hail suppression.

(6) Identify effects of hail damage suppression on precipitation.

(7) Develop systems for hail suppression.

(8) Develop operational programs for hail suppression.

The recommended levels of research and development are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 14 | 26 |
| Thousands of Dollars | 1,800 | 3,950 |

Task 1-d. Modify local winds, temperature and radiation for protection of agricultural and forest resources.

Severe local weather has serious consequences to many activities in agriculture and forestry. Wind from a thunderstorm sometimes produces as much damage as hail. Sudden erratic winds from cloud systems near a forest fire may cause it to spread rapidly. Frost, often developing under conditions of intense radiational cooling, can severely damage a variety of agricultural crops. Extremes of temperature are a problem in many agricultural enterprises.

For many decades man has developed and utilized a variety of approaches to combat extremes in local weather. Tree windbreaks, snow fences, orange grove heat generators and wind machines have been devices to help safeguard against extremes of wind and temperature. Now, weather modification, utilizing methods which may alter causative factors of atmospheric behavior, offers a new opportunity to either augment or replace existing approaches for protection against severe local weather.

Weather modification aimed at local winds, temperature and radiation is a virtually unexplored field. However, general advances in studies of atmospheric behavior and in other aspects of weather modification, provide the rationale for development of new methods to attack local weather problems affecting agriculture and forestry. Some of the possibilities include: timely overseeding of clouds which may form a storm producing severe winds; stimulation of cloud shields to reduce radiational cooling; and reduction of stratus clouds to increase daytime surface temperatures from solar radiation.

An exploratory research program is needed to fully evaluate a variety of approaches to local weather modification aimed at the specific features of local atmospheric behavior in regions producing crops critically sensitive to winds, temperature and radiation. From this exploratory effort a full research program should be developed including the following task elements:

(1) Identify special wind, temperature and radiation problems in various regions of the U.S.

(2) Perform theoretical research and pilot experiments to reduce severe winds and modify atmospheric factors causing frost damage.

(3) Perform field experiments to develop and test technology for preventing the formation of large-scale thunder and hailstorms which produce severe local winds.

(4) Evaluate specific atmospheric behavior factors which produce severe surface winds and determine from these evaluations how combinational weather modification and tree windbreaks may be employed most effectively.

(5) Perform field experiments to develop and test technology for modification of temperature and radiation.

The recommended levels of research and development are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 5 | 8 |
| Thousands of Dollars | 375 | 800 |

2. BIOLOGICAL AND HYDROLOGICAL CONSEQUENCES OF WEATHER MODIFICATION.

Weather modification is justified in large measure by the potentially great, worldwide benefits to agriculture and forestry. To achieve its full potential, we must fully understand effects of weather modification on communities of plants and animals, since this information will provide the basis

for deciding when, where, what kind, and how much weather modification is most suitable. Society, as a whole, then must be involved in determining whether weather modification is the most attractive and acceptable alternative for producing more food and fiber in this nation and improving man's environment.

Real biological dangers have developed from inadvertent atmospheric modification. When intentional weather modification produces long term shifts in weather over large regions, the side effects also may be adverse. Fear of the unknown, conservatism, or romantic naturalism should not stop research on intentional weather modification. Most weather modifications result in only modest environmental changes, not dissimilar in magnitude to those already induced by the widespread uses of fertilizer and irrigation in agriculture. Such changes are not minor, but at the same time, they are not of such character as to prevent careful research even on the intensive scale proposed here, provided we acquire an understanding of biological response to weather alterations. This understanding must come from carefully planned modification and biological research before--not after--some valuable natural resource has been damaged irreparably by sustained and promiscuous cloud seeding operations. This research must include all types of wild and domesticated creatures and landscapes.

The complexity of the plant-animal-weather system boggles the imagination; this complexity requires that a start be made now toward understanding. We must, by field and laboratory observation and measurement and through systematic analysis, learn whether, for example, adding an hour of sunlight, a quarter-inch of rain, or a week of frost-free season would produce five boxes more oranges on a Florida acre or 100 additional board feet of timber on an Arizona acre. The fate of such native plants as goldenrod, sagebrush, and range grasses also must be known.

Clearly a synthetic and experimental ecology is needed. A sound theoretical structure is required which will explain for biological systems and related hydrological systems what is and also what will be. How will temperature, evaporation, and growth change when sunlight or rain is increased or growing season lengthened? How will water supplies be augmented when plant transpiration and evaporation increase following rainfall increases?

The tasks that follow are designed to reach this synthetic system as a basis for rationally and intentionally modifying the weather for our greatest benefit. The research also will advise us on the consequences of inadvertent modification and indicate how best to combat its threats.

Task 2-a. Assess the impact of weather modification upon biological systems.

We must be able to predict the effects of weather or other environmental modifications upon crop yield and productivity, epidemiology and its effect

upon production, crop distribution, and population stability in wild and cultivated regimes. This can be done through systems analysis and stimulations, coupled with studies of the response of plants and animals to controlled changes in their environment. Thus, we can assess most quickly the nature and extent of the expected responses and identify the areas in which new biological information must be developed. This program must proceed at two levels of urgency and planning.

First, we should employ immediately the best of existing models that describe the interaction between organisms and the physical environment. This immediate, short range program should assess, in a preliminary way, the feasibility of modeling the effect of weather modification on biological systems, determine the major features and range of possible results, and identify the critical biological and physical principles involved in each such model.

Because of our ignorance of the biological consequences of weather changes, it is imperative that ecological information be collected coincidently with weather modification experiments to give an early approximate analysis of the probable benefits and hazards. An immediate state of the art analysis also can point up the most serious gaps in knowledge and serve to guide the direction of further research.

Second, a long range systems analysis program is needed to construct increasingly realistic models which integrate biological and atmospheric behavior. This will further aid in planning future experiments and evaluating their results. The long range task should begin with estimates of the benefits that may accrue from increased precipitation on present phenotypes rather than those on improved phenotypes or attempts to predict the long term shifts in cropping practices or in biology change of wild lands.

Last, to predict the effects of weather modification on particular plants or animals, we must know how that organism responds to environmental changes, i.e., how it responds when skies clear or more rain falls. We are woefully short of such information even for common plants, such as corn and wheat. Our knowledge is particularly lacking for diseases and pests, for undomesticated plants and animals, and for the reactions in the soil. This information must be obtained from laboratory environment facilities, field ecometeorological work where key variables are controlled and comparative field ecology. Although existing controlled environment facilities will be used, we will need another controlled environment laboratory devoted solely to biological response to weather modification. Micrometeorological and biological measurement programs, as outlined in Task 2-b, should be mounted to provide the information on the real plant climate and help with the translation of results from controlled experiments to the outdoors.

Studies of crops and natural vegetation which demonstrate a natural adaptability to ranges of rainfall and other climate variables of the order to

be expected by weather modification will be one of the most practical approaches. Crop, range, and forest ecologists should be urged to intensify their field studies, relating response to weather variations through comparative ecology.

The research and development task elements are:

(1) Immediate systems analysis

(2) Long range systems analysis

(3) Climatic responses of plants and animals

The level of support for these elements is:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 15 | 35 |
| Thousands of Dollars | 850 | 2,450 |

Task 2-b. Assess the impact of weather modification upon the physical landscape and the hydrological cycle.

An analysis should be made of the influence of increased or decreased rainfall (frequency, intensity, and duration), radiation, and temperature upon the hydrology of large agricultural and forested watersheds. Increases in urban and agricultural water supplies may be achieved at the expense of increased erosion, floods, and drainage problems. The significance of the total hydrological aspects of weather modification only can be evaluated by a careful and detailed analysis of the physical system.

A research program to provide this information should include a scientific team of hydrologists, soil physicists, and meteorologists to perform a systems analysis approach, and speed development of an adequate model of the hydrological cycle. This model should be based on sound physical principle rather than relying principally on empirical statistical correlation. At the same time, research watershed groups should show early benefits of methods to predict and observe specifically the hydrological results. Ongoing studies of infiltration, percolation and drainage and evaporation should be given sufficiently increased support to permit full exploration of the ramifications of weather modification. For example, new studies as well as examination of established relations between rainfall and runoff should be made in order to understand how increased rainfall, or other changes in temporal distribution, will influence the subsequent surface water and ground water portions of the hydrological cycle. These studies must be coordinated with related research of other agencies.

Research on the relation between weather patterns, snowpack distribution, time and rate of melting, and spring runoff should be expanded and related

to weather modification activities. This will require a substantial augmentation of existing programs.

Erosion is related to rainfall type, intensity and distribution patterns, to the erodibility of the soil and to the density of protective vegetative cover. Change in erosion, sedimentation, and streamchannel stability that may occur as a result of long term enhancement of precipitation should be determined.

The research and development task elements are:

(1) Perform comprehensive studies of the effects of precipitation changes produced by weather modification on runoff and base flow from agricultural and forested watersheds.

(2) Assess effects of snowpack modification upon snow accumulation, snowmelt and runoff distribution.

(3) Examine long term consequences of precipitation modification upon erosion, sedimentation, and streamchannel stability.

The recommended level of support for this task is:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 20 | 32 |
| Thousands of Dollars | 1,200 | 2,240 |

Task 2-c. Learn how micrometeorological processes in the soil-plant-air layers interact with changes in weather systems.

Agriculture and forestry have been systems for local weather modification from the time man first cultivated fields or harvested forests. Man has been altering the energy exchange at the earth-air boundary by changing the balance of evaporative energy exchange through irrigation and through increasing the sunlight captured in photosynthesis. The absorption of solar radiation, both in summer and winter, is changed by cropping and timber cutting. This alters heating of the surface, convection in overlying air masses, evapotranspiration, and melting of snow. Roughness modification by shelterbelts, snow fencing, stubble mulch tillage, and change in the size of forest openings and fields affects the turbulence properties of the airflow over the landscape and the capacity of the air to transport dust, airborne chemicals, snow, smoke, spores, and insects.

An increase in research of micrometeorological processes at the earth-air interface and of related plant environment is necessary for systems analysis of plant response, particularly in translating results from controlled

environments to the outdoors. Systems analysis of hydrological response induced by weather modification practices also requires improved knowledge of meteorological interactions in the soil-plant-air layers. This research also provides a foundation for local climate modification, for developing practices which enhance plant growth, and for favorably altering the hydrological cycle. Basic studies in micrometeorology have the advantage of being widely applicable to many problems; for example, similar turbulent diffusion processes are involved in rural dust storms and in the heat and smog dissipation from cities.

Since drought is the greatest single deterrent to efficient food production and efficient water use, special attention has to be focused on this problem. The control of water loss by crops is intimately related to micrometeorological processes. Consequently, the problems of plant-water relations, changes in availability of soil water for evaporation and transpiration, and plant drought tolerance must be approached through micrometeorological and plant science research.

The research and development task elements are:

(1) Learn how radiation, sensible heat, water, carbon dioxide, spores, and chemicals are exchanged within a plant canopy.

(2) Learn how water moves, is stored, and is released by the soil and how it is transported through the plant.

(3) Develop a comprehensive model that predicts the new microclimates produced through inadvertent and deliberate weather changes.

The recommended level of support for this task is:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 10 | 16 |
| Thousands of Dollars | 600 | 1,120 |

Task 2-d. Monitor biological changes at sites of experiments and active operations in weather modification.

Intensive monitoring studies should measure the actual changes in plants, animals and landscapes at sites of operational weather modification. This monitoring will substitute facts for fears by measuring the actual changes. These measurements also will help to adjust and regulate modification and anticipate adverse effects. The monitored areas will provide tests of theoretical predictions and also provide opportunities for more basic research on the adjustment of species populations to environment.

Monitoring should begin where intensive, deliberate modification experiments are concentrated and where inadvertent modification is suspected. Methods should be developed for the routine biologic evaluation of large-scale deliberate and inadvertent modifications.

Indicator crops and plants, including key native and introduced species and microorganisms, should be selected for observation, and permanent plots established. Communities should be chosen to represent the full range of environments under investigation. Before modification, plant communities should be mapped in detail, then tallied during and after a suitable period of weather modification to determine native specie stability and whether new species have entered the communities. Other plots should be established in similar communities outside the area of modification as independent controls for comparative ecology research. Biological observations should be made on species near the boundary of their ecological range, on animals of limited mobility, on soil microorganisms, and on pests. In establishing such a system of monitoring, full advantage should be taken of suitable stations and plots already observed for many years. At these locations, long term observations may be supplemented by additional measurements to fill the specific needs of the system.

Concurrent with relevant biological measurements at each monitoring station, a complete library of baseline measurements of the physical environment is needed. Such measurements are required for assessing the change in weather as well as for interpreting trends in communities of plants or animals. Environment must be measured within and outside modified areas. For example, we might monitor downwind from cities where changed precipitation and pollution affect organisms; and, as a check, measure in rural, unaffected areas.

Established state experimental farms, Forest Service sites, and USDA field laboratories are excellent locations for monitoring stations. Whenever these locations fit the ESSA "benchmark" program, the stations should be fully instrumented for biological monitoring. The USDA and SAES should support the ESSA benchmark network in every instance as filling a need as vital to agriculture as to ESSA.

The research and development task elements are:

(1) Monitor crops, indicator plants, and microorganisms in areas subjected to specific levels of weather modification.

(2) Monitor native biological communities and introduced indicator species.

(3) Use benchmark environment monitoring stations to evaluate natural and modified weather and the responses of biological systems.

The recommended level of support for this task is:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 10 | 15 |
| Thousands of Dollars | 840 | 1,350 |

Task 2-e. Develop improved agricultural and forestry husbandry to exploit weather changes.

Though weather may be modified primarily to improve existing production practices, experience with new fertilizers and pesticides shows that maximum benefits from a new "environment" requires new husbandry. Thus crops or varieties must be changed, then plant density, water, and fertility, then pest control, and around again until the maximum production is attained from the new circumstances. Since the changes in environment will be rapid and more sweeping than in the past, this iterative adjustment will need to be more comprehensive and rapid and requires the simulations discussed in Tasks 2-a and 2-b. These simulations may early cope with the numbers and kinds of species on a natural site, the rate of growth of plants in a cultivated field, and with predictions of microclimates, but we lack information to deal with the genetic shifts which may occur within species or populations and with the microbiological changes in soils. Very clearly, high priorities must be given to intensifying existing research on physiology and genetics of plant and animal responses to changes in climate.

The task of modifying husbandry for a modified climate will require teams of scientists similar to present-day production groups with plant breeders, environmental physicists, and agronomists or foresters. Specific teams should be assigned to a major crop or vegetation region, for example, to the problems of maize or wheat, of mountain forests, or arid plains. Where weather may be modified primarily to benefit urban interests, we need to learn how to produce good crops under urban environments which may be less desirable for agriculture. This problem will be particularly great for horticultural crops grown in polluted urban atmospheres. Accordingly, the effort of a scientific team should be directed to finding the optimum management of fruits, vegetables, ornamentals, and parks in the new environment of pollution and adversely modified weather in each of the great megalopolis.

The competence of the needed scientists is largely the same as some teams now studying less urgent problems. We urge, therefore, that a USDA lab here, and an agronomy or horticulture department there, be redirected to these urgent present and future adjustments of biology and hydrology. This can be done best with a flexible funding program which will permit immediate and adequate support for interested and qualified groups.

The research and development task elements are:

(1) Develop varieties of major field crops and different management practices best suited to prospective modified environments.

(2) Develop varieties of major horticultural crops and different management practices best suited to polluted and modified environments.

(3) Develop varieties of major forest and range species and different management practices best suited to modified weather.

The recommended level of support for this task is:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 4 | 16 |
| Thousands of Dollars | 240 | 1,120 |

3. ECONOMIC AND SOCIAL ASPECTS OF WEATHER MODIFICATION

Weather modification will have very substantial economic effects on agriculture and forestry. Crop loss from hail; drought; wind or frost damage to growing crops; lightning fires--all suggest potential benefits to agriculture and forestry from weather modification. Large continuing benefits are attainable also, as from increased agricultural output and efficiency, reduced weather uncertainty, and increased water supplies.

It is not possible, at the present state of knowledge, to confine weather modification operations to specific benefit areas. As weather modification involves weather or storm systems of greater complexity, wider areas, more people and their activities will be affected, and more economic and social issues will arise: Can the tangible and intangible losses from, say, rainfall augmentation be measured? Are new means needed for compensating persons adversely affected by weather modification? Can we resolve through law the issues pertaining to modification liabilities? What organizational arrangements are required to initiate, administer, and finance weather modification programs? How should program costs be assigned--to direct beneficiaries, to organized local groups, local or State government, or in other ways? Do present laws serve the need for weather modification without jeopardy to public or private interest in benefited or adversely affected areas?

Weather modification, whether experimental or operational, concerns the economic well-being, property rights, and attitudes of many people. A research program aimed at gaining an understanding of these issues concerning weather modification is fundamental to the success of the overall

enterprise. Unless the research dealing with the atmospheric and biological aspects of weather modification is accompanied by development of a thorough understanding of the economic and social aspects, the venture will not realize its full potential.

This program is heavily dependent upon information developed from both basic and applied physical and biological studies discussed in preceding sections. It is especially important, therefore, that social scientists cooperate closely with scientists in other fields to become familiar with the technical possibilities of weather modification and assist, as appropriate, in designing studies to measure and evaluate the effect of weather modification.

Task 3-a. Assess the economic effects of weather modification on agricultural and forest resource management, production and protection.

As weather modification science develops there will be specific information on the degree to which various weather elements may be altered. For example, in various regions this information may show that winter snowpack can be increased by 15 percent; fire setting lightning strokes reduced 35 percent and the chances for damaging hail reduced by 50 percent. These changes should be evaluated from an economic viewpoint.

Weather modification experiments indicate that atmospheric behavior can be altered. Economic studies should begin now to develop information needed in determining priorities for specific phases of weather modification. A continuing program of economic studies, carried out in cooperation with other disciplines, is needed also to supply information and analysis relevant to policy issues involving weather modification. Is weather modification an efficient means of obtaining a needed product or service, e.g., hail protection? What is the extent and economic significance of off-site or external effects of weather modification? How do alternative means of compensating disbeneficiaries affect on-site values of weather modification?

Initial emphasis should be given to determining economic feasibility of modifications nearest to operational status. These include snow and rainfall increase, hail suppression, and lightning suppression. Later research should examine regional and national significance of weather modification for water resources development, agricultural production, and other significant economic activities.

The research and development task elements include studies to determine:

(1) Regional and national costs and benefits of weather modification measures.

(2) Productivity relationships in agriculture and forestry of weather modification measures.

(3) Extent and incidence of secondary or off-site costs and benefits of weather modification.

(4) Effects of regional and national weather modification programs on aggregate agricultural production, regional production patterns, farm income, and land values.

(5) Importance of weather modification programs for regional and national development of water and related land and forest resources.

The recommended levels of research and development are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 10 | 24 |
| Thousands of Dollars | 450 | 1,200 |

Task 3-b. Develop knowledge for attacking social and legal problems associated with weather modification.

Man reacts strongly to weather. He reacts even more strongly to efforts to change nature's weather processes. Scientific endeavor should make an objective evaluation of whether or not this change is beneficial.

A number of states are exercising some form of regulation over weather modification ranging from licensing or filing prior notice of operations to outright prohibition of such activities. The Congress of the United States is considering legislation dealing with these problems as well as with questions of who does or should control the atmosphere--the States, the Federal Government, an interstate or international organization?

The social and legal aspects of weather modification are of concern to many groups. This concern has major implications for agriculture and forestry in view of the great potential benefits to be realized from measures such as precipitation increase, and hail and lightning suppression. Uncertainty about the effects of cloud seeding and of the magnitude of weather changes brought about, and the impossibility of avoiding off-site effects are among the reasons measures are enacted to regulate or prohibit weather modification.

Given the present interest in weather modification measures that so heavily concern agriculture and forestry, the Department of Agriculture and the State Agricultural Experiment Stations have an opportunity and an obligation to gain knowledge about the social and legal issues of weather modification and the means of resolving them. Emerging questions include what regulatory powers the States and Federal agencies should exercise over weather modification and who is responsible for damages caused by weather

modification. Can such damages be covered adequately by insurance or are other arrangements needed? Special districts have been suggested as a means for internalizing the benefits and costs of weather modification but there are problems of adequately defining district boundaries for this purpose. Issues such as these are broadly illustrative of the social and legal problems to which research should be directed. As weather modification activities progress from experimentation to actual operation, the means for resolving crucial social and legal problems must be available.

The research and development task elements include studies to:

(1) Formulate guidelines to use in developing institutional arrangements for managing weather modification operations at the site or area of operations.

(2) Evaluate alternative arrangements for managing weather modification operations, such as special districts, with attention to authority for financing, regulating, licensing, and monitoring operations; designation of area and relationship to local and State governments.

(3) Analyze legal aspects of weather modification in relation to agriculture and forestry; determine judicial, legislative, and organizational requirements to facilitate weather modification experimentation and operations.

(4) Determine how individual attitudes toward weather modification are formulated.

The recommended levels of research and development are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 8 | 15 |
| Thousands of Dollars | 360 | 750 |

4. DECISION-MAKING IN WEATHER MODIFICATION

Task 4-a. Develop knowledge for decision making and resolving policy issues in weather modification.

Weather modification experiments are already underway in many agricultural and forest regions. Many more experimental operations will take place in the near future. During the next 5 to 10 years, as weather modification science develops, there will be many decisions required about proposed operations: Is weather modification the best alternative for solution of a regional agricultural or forestry problem? To what extent shall national and regional water resource needs affect priorities in the total weather

modification program? How will off-site effects be handled? What activities, if any, can be exempt from regulation? How shall regulatory responsibilities be allocated between the State and Federal Government?

These and many other decision questions are basic in defining policy and carrying out long-range programs of weather modification research and development. Over time, information needed to resolve policy issues should come from the total national program in weather modification research. But this information often will deal only with technical segments of the questions. A decision-making process is needed to provide reliable and complete answers. Precedence for resolving policy answers pertaining to weather modification cannot be found in other programs.

It is proposed that an interdisciplinary team be established early in the program to provide expert assistance in identifying, analyzing, and resolving policy issues pertaining to weather modification. Input to this team effort will come from all segments of the USDA-SAES program as well as from weather modification research and operations provided by other groups. As this activity becomes well established, research should be undertaken specifically to develop models of and analyze the decision-making process for weather modification operations affecting agriculture and forestry. Major attention would be given to identification of program goals and analyzing alternative means for meeting them, taking account of ecologic, hydrologic, and socioeconomic effects.

Research task elements in this area include:

(1) Criteria for weather modification decisions.

(2) Development of models for weather modification decisions.

(3) Study of associated requirements for regulation of weather modification.

The recommended levels of research and development are:

| | FY 1972 | FY 1977 |
|---|---|---|
| Scientist Man-Years | 4 | 8 |
| Thousands of Dollars | 240 | 480 |

# III. RESEARCH RESOURCES

## A. Research Manpower

The first and most important requirement of the weather modification research program for agriculture and forestry is scientific manpower. The FY 1972 goals require 124 scientists and double that number in FY 1977. In addition the program requires a larger number of technicians, temporary field and laboratory assistants, logistic support personnel and administrative specialists. The total program will involve about 300 employees in 1972 and some 750 in 1977.

These are relatively modest personnel requirements in view of the magnitude of the enterprise. These modest requirements are predicated on the redirection of some current USDA and SAES personnel from closely allied research. However, the requirements are critical for additional highly skilled scientists in the special fields of weather modification involved in the agricultural and forestry program as proposed in the above manpower requirements. These include: atmospheric physicists experienced in both theoretical and field experimental aspects of cloud seeding; engineers and other scientists with backgrounds for weather modification instrumentation; biologists, ecologists, soil scientists and hydrologists with knowledge of both the atmospheric and plant-animal-soil-water variables involved; and economists and social scientists with a keen insight to natural resource factors as well as those of their own professional field. In addition this program requires persons with ability to plan, manage and carry out field activities involving sophisticated instrumentation, operation of a variety of aircraft, support of people at remote stations and effective coordination of interdisciplinary efforts.

While the manpower requirements are stringent, there is ample evidence that they can be met. USDA experience in weather modification research already has provided a background of experience that will help in planning and managing future scientific manpower activities. Increasing the level of effort to 124 scientists by 1972 and 242 in 1977 can be accomplished through application of personnel management know-how available in USDA and SAES.

It is estimated that about 60 percent of the planned program will be performed in-house by USDA agencies and State Agricultural Experiment Stations. Some 40 percent of the effort will be accomplished by cooperating universities, private research organizations and other Federal or State agencies. This ratio may vary according to existing situations. The research should be performed by whatever organizations that have the greatest competence and can make the best progress.

The following is an estimate of the types of scientists required for the 1972 and 1977 manpower goals:

| | 1972 | 1977 |
|---|---|---|
| Research Meteorologists | 30 | 43 |
| Atmospheric Physicists | 6 | 10 |
| Physicists | 4 | 6 |
| Chemists | 1 | 1 |
| Electronic Engineers | 6 | 13 |
| Aeronautical Engineers or Specialists | 3 | 5 |
| Hydrologists | 4 | 8 |
| Research Foresters | 14 | 29 |
| Biologists and Ecologists | 19 | 38 |
| Soil Scientists | 7 | 12 |
| Economists | 9 | 14 |
| Mathematicians | 2 | 9 |
| Operations Research Specialists | 2 | 4 |
| Social Scientists | 8 | 15 |
| Agricultural Resource Specialists | 9 | 35 |
| Total | 124 | 242 |

B. Scientific Facilities

Existing scientific facilities operated by USDA agencies, State Agricultural Experiment Stations and cooperating universities and other organizations can provide essential support for initial research efforts. These facilities must be augmented by additional field and laboratory installations designed especially for support of the USDA-SAES weather modification research program. These include the following:

Lightning Suppression

The Forest Service Northern Forest Fire Laboratory, Missoula, Montana, contains special facilities for support of lightning research. At an early date, the Forest Service plans to construct an addition to this laboratory which will provide some of the other facilities needed for support of the weather modification research program. In addition, the laboratory facilities described under General Atmospheric Sciences will provide other needed laboratory support.

Field experimental areas for lightning suppression research are available on several western National Forests. Initial large-scale experiments will be performed in Montana-Idaho National forests. The experimental area will be instrumented with a network of lightning sensor stations, radar units, automatic cameras and atmospheric probing equipment. Much of the data will be transmitted to a central recording point and transferred to magnetic tape for automatic data processing. Funds for the field instrumentation program are included in the proposed lightning research budget.

Future lightning suppression research and operating programs will require additional facilities for remote sensing of lightning. During the next decade it is likely that a combination of ground sensor stations and satellite observations will permit rapid recording and evaluation of lightning in all major thunderstorm regions. Part of the costs for development of this remote sensing system are included in the proposed USDA budget. Eventual installation of the system will require a major capital investment involving several Federal agencies. These funds are not included in the proposed program.

Hail Suppression

One of the major requirements for hail suppression research is a large fully instrumented experimental area in a region of intense and frequent hailstorm activity. During initial experimental activities it is desirable for this area to be largely public land where full control can be maintained of the site and activities. An airspace reservation may be needed over the area to permit use of a combination of rockets, artillery shells, aircraft and balloons in the experiments.

A prospective hail suppression experimental area is the Pawnee National Grasslands in northeastern Colorado. Investigations will be made of other possible experimental areas. It is recommended that the Department of Agriculture participate with other agencies in developing and fully instrumenting the necessary experimental area for performance of the national hail suppression research program. Funds for general field instrumentation are included in the proposed budget. Major units such as large radars and a large-scale hail sensing network will require additional funds.

Special laboratory facilities will be needed for the hail research program. Some of these facilities may be provided by other agencies and universities. For example, Colorado State University is planning a wind tunnel and cloud chamber to meet specific needs of hail research. Additional USDA needs are shown below.

General Atmospheric Sciences

The Forest Service plans to develop a forest meteorology laboratory in cooperation with Colorado State University at Fort Collins. This laboratory will include special facilities for research in atmospheric physics, mountain meteorology, fire danger rating and weather modification technology. Capital investment for this laboratory is estimated at $1.5 million. It is recommended that studies be made of possible use of this laboratory together with any necessary additions for support of the USDA weather modification program and especially the hail suppression research.

Aircraft

To date most of the aircraft needed for support of lightning suppression research have been contracted from private firms. This includes aircraft for cloud seeding and measurement of atmospheric factors.

In the expanded program many of the aircraft requirements can continue to be met by contractual arrangements or cooperation with other agencies. However, in future lightning and hail suppression programs there will be a need for high performance aircraft. These aircraft will be used for remote sensing of lightning and hail and measurement of factors in the interior portions of clouds. Safety considerations and high altitude flight needs dictate that such aircraft must be very strong, stable and powerful. Meeting these needs may require government purchase of the aircraft. It is estimated that a capital investment of $2 million will be needed for aircraft and special instrumentation.

Biological Research

Both instrumented field experimental areas and special laboratory facilities will be needed for support of research on the biological consequences of weather modification. Most of the field areas will be at the sites of

weather modification projects. Funds for instrumentation of these areas are included in the program estimates.

The biological research program needs laboratory facilities providing environmental control for experiments of biological responses to weather changes. As part of the total program in this field there should be a national laboratory that will be a major focal point for detailed experiments of phenomena related to the complex interactions of variables at the earth-atmosphere interface. A biotron installation in this laboratory will permit needed progress on studies which bridge the gap between theoretical investigations and field observations. The high costs of such a facility require that this type of research be concentrated at a single location to serve national needs. It is estimated that a national biological-atmospheric research laboratory will require a capital investment of $7 million.

C. Research Organization

The proposed weather modification research program for agriculture and forestry involves a multidisciplinary, multiagency effort of great depth and magnitude. With participation by four USDA agencies, (ARS, CSRS, ERS and FS) many State Agricultural Experiment Stations and many universities and cooperating agencies, it is essential that a workable organizational structure be developed to tie the program together. This program must have a central scientific focal point.

Several alternatives are possible for establishment of a focal point which will provide necessary scientific leadership and coordination. These include:

1. Establish a USDA institute or center for weather modification research. This would be staffed by a small group of scientists with specialties in direct modification of weather and the biological, hydrological, economic and social aspects. They would provide the scientific leadership for overall program planning and coordination. The research would be performed by USDA agencies, State Agricultural Experiment Stations and cooperating organizations. However, there would be constant scientific contact between the center or institute and the research doing units. USDA could assign responsibility for operating the center or institute to a single USDA agency or could operate it by a cooperative arrangement between the several agencies concerned. The center should be at a field location having a good scientific environment for weather modification research.

2. Establish separate national centers or institutes for each of the three major aspects of the program -- direct modification of weather, biological and hydrological consequences, and economic and social aspects. Each of these centers would function in its field in the same manner as the single national center outlined above. The three centers would maintain constant communication with each other and should have an interlocking

committee or board of directors. The USDA has demonstrated capability in direct modification and the Stations have demonstrated capabilities in biology and economics. Therefore, the center for direct modification, located in the area where much of the direct modification research on fire and hail would be done, could wisely be made a primary responsibility of the USDA. The center for biological and hydrological consequences could wisely be made part of a State Experiment Station that has excellent research in these matters and complementary facilities. More study and the development of a social science and economics staff attuned to the special problems created by weather modification technology will lead to the establishment of a lead center for this area of research.

3. Assign responsibility for each major technical phase of the program to a USDA agency. Each of these agencies would establish a central scientific focal point for its weather modification research program. Interagency coordination would be achieved by an interlocking committee or board of directors.

These and other alternatives should be given careful consideration in developing a needed scientific coordination mechanism. It is recognized that existing budgeting, administrative and organizational procedures complicate this matter. It is recommended that the scientific organization be made to fit the research requirements rather than the reverse concept of making the research fit existing organizations. USDA has a vital mission in weather modification. It needs the best possible scientific organizational structure to assure fulfillment of this mission.

APPENDIX TABLE 1

Summary of Scientist Man-Years and Dollars
for each Weather Modification Research Goal

| TASKS | FY 1972 | | | | FY 1977 | | | |
|---|---|---|---|---|---|---|---|---|
| | USDA | | SAES | | USDA | | SAES | |
| | SMY | $K | SMY | $K | SMY | $K | SMY | $K |
| 1-a Precipitation | 8 | 800 | 4 | 200 | 15 | 1,500 | 12 | 720 |
| 1-b Lightning | 12 | 1,800 | 0 | 0 | 20 | 3,500 | 0 | 0 |
| 1-c Hail | 10 | 1,500 | 4 | 300 | 18 | 3,150 | 8 | 800 |
| 1-d Wind, Temp. Radiation | 2 | 150 | 3 | 225 | 4 | 400 | 4 | 400 |
| Sub Total | 32 | 4,250 | 11 | 725 | 57 | 8,550 | 24 | 1,920 |
| 2-a Biological Systems | 10 | 600 | 5 | 250 | 20 | 1,400 | 15 | 1,050 |
| 2-b Physical Landscape and Hydrology | 10 | 600 | 10 | 600 | 12 | 840 | 20 | 1,400 |
| 2-c Micrometeorological Processes | 5 | 300 | 5 | 300 | 8 | 560 | 8 | 560 |
| 2-d Monitor Biological Changes | 6 | 600 | 4 | 240 | 10 | 1,000 | 5 | 350 |
| 2-e Agricultural & Forestry Husbandry | 2 | 120 | 2 | 120 | 8 | 560 | 8 | 560 |
| Sub Total | 33 | 2,220 | 26 | 1,510 | 58 | 4,360 | 56 | 3,920 |
| 3-a Economic Effects | 5 | 225 | 5 | 225 | 12 | 600 | 12 | 600 |
| 3-b Social and Legal Aspects | 4 | 180 | 4 | 180 | 7 | 350 | 8 | 400 |
| Sub Total | 9 | 405 | 9 | 405 | 19 | 950 | 20 | 1,000 |
| 4-a Decision Making | 4 | 240 | 0 | 0 | 4 | 240 | 4 | 240 |
| Sub Total | 4 | 240 | 0 | 0 | 4 | 240 | 4 | 240 |
| GRAND TOTAL | 78 | 7,015 | 46 | 2,640 | 138 | 14,100 | 104 | 7,080 |